AIR CONDITIONING AND REFRIGERATION
Journal
The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers

Issue : April-June 2000

Alternatives for R-22 in Split System Air Conditioners

By: Lawrence Chin

Technical Manager - Asia Pacific

Honeywell International Inc.

Singapore

&

Mark Spatz

Technical Manager - North America

Editor's Note

AlliedSignal Inc., a manufacturer of refrigerants among other products and Honeywell, a manufacturer of automatic controls merged into one entity about two years ago. The joint entity goes by the name Honeywell International Inc.

R-22 refrigerant is slated for gradual reduction, starting in 2004 and complete phase-out by 2030 in developed countries and 2016/2040 in developing countries such as India.

This article addresses the application of he three principle alternatives for R-22. They are R-134a, R-407C and R-410A. The application studied is split system unitary air-conditioners that are in common use in the U.S. The article is divided into two segments. The first segment presents an analysis of the impact of each refrigerant on the system performance. In the second segment, an analysis of the impact on manufacturing cost was performed on the two refrigerants that exhibited the best performance from the first segment, namely R-407C and R-410A. The performance/cost modeling was performed using a system performance computer model[1] to optimize the design around the particular refrigerant to achieve the same capacity and efficiency as R-22 at the lowest cost. The results show potential cost saving for R-410A and led to the conclusion that this refrigerant would be the replacement of choice for R-22 in this application.

Background

The search for the optimal replacement of R-22 in unitary air conditioning systems has been narrowed down to three refrigerants. They are R-134a, R-407C and R-410A. R-134a is a single component refrigerant, R-410A is a binary mixture of HFC-32 and 125 that exhibits azeotrope-like characteristics, and R-407C is a ternary blend of HFC-32, 125 and 134a. Each refrigerant has a different vapour pressure characteristic which in turn generates other properties. R-134a has lower pressure (about 30% lower) than R-22, R-407C has similar vapour pressure (about 10% higher), and R-407C would seem to be the best choice to replace R-22 , but its zeoptropic behaviour creates production difficulties (during blending and packaging 2, 3) and potential operational and service problems (fraction during leak 4) as well as impacting the heat transfer performance. It is therefore, necessary to investigate additional criteria before selecting the best candidate.

Impact of Refrigerant on System Performance

The impact of the choice of refrigerant on system performance is significantly more complex than just the role of thermodynamic properties cannot be ignored, the impact of heat transfer and pressure loss characteristics can easily dominate the refrigerant's impact on system performance. This is especially true for unitary air conditioning systems where the temperature lift is relatively small. Transport properties will play a major role in the performance of compressors, heat exchangers, and interconnecting piping.

Approach

To understand this complex relationship between refrigerant properties and system performance, an evaluation of both system modeling was used[5] .There has been a considerable amount of system tests performed with R-22 alternatives over the last several years. In order to better understand the results of these tests, computer simulations of systems running with R-22 and alternatives to R-22 were conducted. These system simulation models use the refrigerant's thermo dynamic and transport properties along with maps of compressor performance based on compressor calorimeter tests to predict the performance of the system. Using this approach the total impact of the refrigerant change is evident.

Results

Table 1 displays the results of a series of tests that were conducted at a recognized independent testing laboratory, ETL. These tests were run on a typical 2½ ton (8.8 kW) split system air conditioner in co-operation with the equipment manufacturer.

Table I: Air Conditioner Tests (% of R-22 Performance)

	R-410A (Scroll Compr.)	**R-410A (Recip. Compr.)**	**R-407C (Counterflow)**	**R-407C (SLHX)**	**R-134a (SLHX)**
Test "A" Capacity	99%	102%	98%	97%	100%
Test "A" COP	105%	104%	89%	95%	94%
Test "B" Capacity	100%	105%	101%	98%	100%
Test "B" COP	105%	106%	92%	96%	94%

For both R-410A and R-134a the compressor was replaced with a similar compressor that had either a smaller (for R-410A) or a larger (for R-134a) displacement. This was done in order to maintain the same capacity as R-22. The number of parallel refrigerant circuits was optimized for the given refrigerant. For R-410A the number of circuits was reduced by one third, whereas for R-134a, the number of circuits was doubled. For R-407C the circuits in the evaporator were reconfigured to achieve a "quasi-counterflow" arrangement with the air flow in an attempt to take advantage of the temperature glides of the refrigerant (since "glide" affects the efficiency of a heat exchangers, a "quasi-counterflow" helps to reduce the efficiency penalty due to the glide problem). For R-134a and R-407C, a heat exchanger was added to exchange heat between the suction and liquid line (noted by SLHX).

Tests were run at standard conditions "A" and "B". Condition "A" corresponds to a 35°C outdoor temperature and is used to rate the capacity of the air conditioner. Condition "B" Corresponds to an outdoor temperature of 28°C and is used to evaluate system efficiency at a seasonal average temperature.

The test results show a 5 to 6% improvement in COP for R-410A and a 8% decrease in COP for R-407C. Using an additional heat exchanger (the SLHX) the decrease in COP for R-407C drops to 4% Even with the SLHX, the system running with R-134a still sees a 6% drop in efficiency.

Table 2 summarizes the overall impact of the three refrigerants with respect to R-22 performance. It is based on information from system tests such as the one previously discussed and from system modeling. The system here refers to a unitary split system with a single evaporator. In this system, R-410A is a clear winner to replace R-22. Although R-

410A has a 7% reduction thermodynamic performance, it has superior transport properties that yield a net gain of 5% in overall efficiency.

Table II

Efficiency Effect (%) Relative to R-22	R 134a	R-407	R-410A
Thermodynamics	+ 2	- 4	-7
Compressor	- 3	- 1	+5
Heat exchanger	- 6	- 2	+2
Lines	- 2	0	+2
Total (net)	- 9	- 7	+5

Although R-134a has superior thermodynamic performance compared to R-22 and the other two refrigerants, the net effect of all its properties on system performance is negative. Basically the gas in from the increase in thermodynamic efficiency (typically lower pressure refrigerants to have higher thermodynamic efficiency) is more than offset by higher heat exchanger and inter-connecting line pressure drops and poorer heat transfer.

On the other hand, the higher working pressure refrigerants like R-410A have better transport properties, which translated into better heat transfer and lower pressure drop8. These are also the main reasons for the shift from R-12 to R-22 for most air conditioning applications in the 1950s.

Based on compressor performance, R-410A has better results due to lower flow losses and better and better heat transfer. Superior transport properties primarily impact the performance of heat exchangers and interconnecting lines, although these properties often impact compressor performance as well.

Since R-407C is essentially a mixture of R-134a and R-410A, it is not surprising that the overall performance of R-410A. The poorer heat transfer of R-407C reduces the efficiency to a level closer to R-134a.

Performance/Cost & Evaluation

In the United States, the efficiency of most unitary equipment is dictated by minimum efficiency standards. Presently, the minimum SEER, seasonal energy efficiency rating, is at 10.0 (equivalent to 2.7 COP). This value may be raised to 12.0 SEER (3.3 COP) in the near future. Computer simulations were conducted to assess the most appropriate alternative for equipment based on the present efficiency standard and also for equipment to meet higher SEER regulation.

Basics of Refrigerants

Definition

A refrigerant is a medium (fluid) for heat transfer, used in a refrigeration system to pick up heat by evaporating at a low temperature and pressure, and to give up heat upon condensing at a higher temperature and pressure.

Number Designation

Refrigerants are identified by number, preceded by the letter "R" (refrigerant). This number designation has been established by ASHRAE and is used throughout the industry.

Certain designations have been provided for the refrigerants in abbreviated form, to indicate the chemical composition, as well as to relate to the Ozone Depletion Factor (ODF) for the refrigerant. (ODF is a rating with a range of 1 - 0). For example, refrigerant R-12 can be designated CFC-12, R-22 can be designated HCFC-22 and R-134a can be designated HFC-134a.

Chemical Composition of Refrigerants

Common refrigerants are listed in the table below along with their chemical name and the ODF. The prefix "CFC" refers to the family of refrigerants containing chlorine, fluorine and carbon. Compouinds that also contain hydrogen precede the abbreviation with the letter "H" to signify an increased deteroration potential before reaching the stratosphere - for example the prefix "HCFC". The "FC" family does not contain chlorine and can also be preceded with an "H" as in "HFC".

Characteristics of Some Common refrigerants

"R" Number	Chemical Type	ODF	Similar To	Components
R-11	CFC	1.00		11
R-12	CFC	1.00		12
R-22	HCFC	0.05		22
R-123	HCFC	0.02		123
R-134a	HFC	0.00	R-12	Single
R-401a	HCFC	0.05	R-12	22,152a,124
R-402b	HCFC	0.02	R-502	125,290,22
R-404a	HFC	0.00	R-502	125,143a,134a
R-500	CFC	0.74		12,115
R-502	HCFC	0.28		22,115
R-507	HFC	0.00	R-502	125, 143a

Note that the CFC refrigerants have a high ODF; the HCFC refrigerants have a low ODF and the HFC refrigerants have a zero ODF.

Certain refrigerants which are mixture, use the R number and also have a designation that shows the constituents. For example, R-502 is composed of HCFC 22/115. the ODF given is a 0.28 rating.

Azeotropic and Zeotropic Blends

A number of refrigerants, such as R-502, are made up of blends or chemically prepared mixtures of refrigerants.

The azeotropic blends consist of multiple components of different volumes that, when used in refrigeration cycles, do not change volumetric composition or saturation temperature as they evaporate or condense at constant pressure. These refrigerants have numbers in the 500 series, such as R-502, r-507, R-508 etc. In simpler terms an azeotropic blend is very stable, or difficult to separate, has a negligible glide and can be charged in vapour or liquid state.

The zeotropic blends are just the opposite and the components can be separated easier than azeotropes, have some glide and can only be liquid charged. The designated numbers are 400 series such as R407C, R404A, R401A, R402A etc.

Temperature Glide

Temperature glide occurs in both an evaporator and a condenser. In an evaporator at constant pressure the refrigerant blend begins to boil at one temperature and finishes boiling at a higher temperature. The difference in these boiling temperatures is called "Temperature glide". This also occurs in a condenser, except that the temperature decreases as the refrigerant vapour condenses. Temperature glide is associated with near-azeotropic refrigerant blends.

Considerations for using Near-Azeotropic blends

Common refrigerants used in the past were either single component, or azeotropic blends which behaved as a single component when used in a refrigeration system. Near-azeotropic blends will behave almost the same as azeotropes, for all practical purposes.

Basically, the computer simulation consists of two main components; performance modeling and cost modeling. The performance modeling was based on ORNL Heat Pump Design Model 1 that can handle R-410A and R-22, but not R-407C. For R-407C refrigerant simulation, the heat transfer coefficient of R-22 was degraded by 20% and R-407C compressor efficiency was set at 96.5 % of R-22 to stimulate the thermodynamics of R-407C. The heat transfer coefficient for R-407C is about 20% lower than R-22 for refrigerant flow inside a tube 7.

In cost modeling, there are three modules that were developed internally: coil cost, sheet metal cost, and packaging cost. Coil cost includes labour and overhead Cost. This modeling is applicable to condensing and evaporator units. The cost of compressors and refrigerant were not included in the modeling. It is anticipated that the compressor cost would be increased due to more expensive esters oil and possible bearing & sealing changes. The amount of refrigerant can be determined by the internal volume of the coils and inter connecting tubing.

Modeling Approach

An R-22 air conditioner was used as a baseline for comparison. An evaluation of 2.7 and 3.3 COP systems was conducted. Design constraints were imposed in order to ensure that the simulation results were practical. The maximum condenser coil height was limited to 76cm (2.7 COP) & 91 cm (3.3 COP) and the maximum condenser length was limited to 137 cm. Evaporator face area could not exceed baseline values and the condenser airflow could vary from 991 L/s (2100 cfm) to 1227 L/s (2600 cfm). The parameters that were varied were tube diameter, circuiting of tubing, fin spacing, number of rows, internal smooth or rifled (grooved) tube type, and compressor efficiency. Two values of compressor efficiency were used, the same as R-22 or 5% higher (for R-410A only)

R-407C

Due to its poorer heat transfer properties, the cost of producing the coils sheet metal and packaging of a condensing unit with similar performance as R-22 (3 Ton or 10.5 kW) increased significantly. In addition, there was a 25% increase in condenser airflow. The size and cost increases, rifled tubing was used. This reduced the cost increase over the R-22 unit by about half of the original increase.

R-410A

By using a nominal R-410A compressor (same efficiency as baseline R-22 compressor), a cost savings can be realized. Furthermore, the tube diameter and thickness were smaller and hence the overall unit would become more compact. Similarly, the optimized evaporator unit (A-shape) yields a substantial cost saving. The cost savings on the condenser unit can be in-ceased further if a 5% higher efficiency compressor was to be used.

In anticipation of a higher SEER requirement (e.g., 3.3 COP), a R-410A condensing unit was simulated using a currently available high efficiency scroll compressor.

It is anticipated the cost increase of the R-410A refrigerant will he partially offset by lower charge size due to smaller internal volume of coils. However, the compressor cost is expected to be higher than R-22 R-410A and the more expensive POE lubricant. A summary is shown in **Table III**.

Further decreases in condensing unit cost could be realized due to the reduced air flow requirement for R-410A units. Savings in the cost of the fan motor should motor should result from the lower flow requirements. R-407C units would likely have cost increases in this area.

Table III

Description	R-22	R-407C		R-410A		
COP	2.7	2.7	2.7	2.7	2.7	3. 3
Notes	Baseline	Degraded R-22	Rifled Tube	Nominal Efficiency Comp.	5% Higher Efficiency Comp.	Currently Available Scroll
Compressor	Recip.	Recip.	Recip.	Recip.	Recip.	Scroll
Coil Cost	$51.91	$72.49	$63.70	$48.10	$33.59	$40.05
Sheet Metal & Packing	$19.35	$22.63	$18.75	$17.00	$14.29	$15.99
Coil, Sheet Metal, & Pack. Cost	$71.26	$95.12	$82.45	$65.10	$47.88	$56.04

Conclusions

There is high potential for significant material and labour savings for air conditioning systems with R-410A refrigerant. There is a consensus within the air conditioning industry that R-410A is the leading replacement for R-22 in unitary air conditioning systems.

R-407C requires more surface to yield comparable performance to R-22 which increases manufacturing cost. However, R-407C will find use as a refrigerant for systems currently using R-22 once R-22 is no longer available for service.

R-134a will likely be used in large systems where the high pressure of R-410A is too great a barrier and the temperature glide of r-407C prohibits its use (such as systems with flooded evaporators).

References

1. Rice, C. and Jackson, W., PUREZ- The Mark V ORNL Heat Pump Design Model for Chlorine-free, Pure and Near-Azeotropic Refrigerant Alternatives, Oak Ridge National Laboratory, 1994.
2. Hughes, H.M., Dulaney, W.P. and Broussard, R.L., A Refrigerant Producer's Experience in Manufacturing Zeotropic Blends, Proceeding of the 1996

International Refrigeration Conference at Purdue, Purdue University, West Lafayette, Indiana, 1996.

3. Pieczarka, Pand Lavelle, J., Storage, Bulk Transfer and In-Plant Handling of Zeotropic Refrigerant Blends, Proceeding of the 1996 International Refrigeration Conference at Purdue, Purdue University, West Lafayette, Indiana, 1996
4. Stabouly, S. and Wesolowski, A., Serviceability Issues Associated with R-407C Refrigerant, Proceeding of the 1996 International Refrigeration Conference at Purdue, Purdue University, West Lafayette, Indiana, 1996.
5. Spatz, M. and Zheng, J., Experimental Evaluation of R-22 Alternative Refrigerants in Unitary Air Conditoning Equipment, Proceedings of the 1994 International Refrigeration Conference at Purdue University, West Lafayette, Indiana, 1994.
6. Furuhama, K. Toshiba Corporation, Private Communication
7. Okazaki, T. Mitsubishi Electric Corp., Private Communication.